3. Reverse Band Utilization of Fixed-Satellite Service Allocations May Be the Least Problematic Accommodation in the U.S. But Not Elsewhere

Somewhat more feasible, but certainly not problem-free, is the possibility that NGSO feeder links may be accommodated in existing FSS allocations by transmitting in the opposite direction of conventional FSS systems (e.g., Earth-to-space in current space-to-Earth allocations). This scheme, known as reverse band utilization, has been proposed several times over the years as a way in which additional FSS spectrum could be obtained. In preparation for the WARC-ORB Conferences, NASA conducted an extensive study of the feasibility of reverse band utilization in the hope that the additional FSS spectrum so obtained could eliminate the perceived need for allotment plans. The study revealed that the associated frequency sharing was workable through the adoption of design and operating standards for systems working in the new directions of transmission. However, the technique was judged infeasible because the other services that operate in all FSS allocations could not withstand the additional interference from FSS systems. Thus, while reverse band utilization may be feasible in the U.S. for NGSO feeder links in certain bands not greatly used by other services (e.g., 11.7-12.2 GHz), these same bands are in all cases used extensively outside the U.S.

4. Sharing by Means of RR No. 2613 Provisions Would Be Costly

Presently, NGSO FSS systems are accommodated under the principles of RR No. 2613, which requires that NGSO systems cease or reduce their emissions when necessary in order to prevent unacceptable interference to GSO FSS systems. Reduction of the emission power from NGSO systems is unlikely to be feasible, however, because those systems would already be operating near the minimum satisfactory power level. Cessation of emissions in the feeder uplink direction would be possible provided that the feeder uplink traffic could be switched to another feeder link earth station located sufficiently distant from the initial earth station to afford adequate antenna discrimination toward the victim GSO satellite. In order to accomplish this, the geographic density of feeder link earth stations must be substantially higher than the minimum density needed in the absence of the interference problems. A similar technique could be used in the feeder downlink direction, whereunder the offending NGSO traffic is switched to a different satellite antenna or spot beam that provides ample discrimination toward the victim FSS earth station. The required additional feeder link earth stations and the alternate satellite antennas or antenna beams would greatly increase the cost of the NGSO systems.

B. Design and Operating Constraints on NGSO Downlinks

1. Interference From Industrial, Scientific and Medical (ISM) Equipment Operating in the 2400-2500 MHz Band

As established by measurements conducted by NTIA and others, microwave ovens operating in the ISM allocation at 2400-2500 MHz would generate debilitating interference to NGSO systems using the 2483.5-2500 MHz band. The received noise power from ovens can equal or exceed the inherent noise power of NGSO mobile earth stations, particularly in handheld terminals, because of their lack of antenna discrimination. Making matters worse is the fact that in addition to the over 80 million microwave ovens in the U.S., there are countless other industrial, medical and consumer devices that radiate substantial interfering emissions in the 2483.5-2500 MHz band, including plywood driers, plasma exciters used throughout the plastics industry, high-efficiency lights that are being implemented to reduce electrical energy demand, and diathermy machines. This not only would pose a formidable reliability problem for rural users of CDMA NGSO MSS systems, but also would ensure that NGSO CDMA handheld terminals cannot be used in or near urban and suburban areas given the lack of adequate link power margin already manifest in all the proposed CDMA NGSO systems.

2. Interference To and From Systems in the Fixed and Mobile Services

As a result of earlier allocation actions with regard to the radiodetermination-satellite service ("RDSS"), the Commission is not issuing new licenses for terrestrial systems in the 2483.5-2500 MHz band. Nonetheless, there are over 700 grandfathered U.S. terrestrial systems as well as tens of thousands of foreign terrestrial systems that can interfere with MSS mobile earth stations and which must be protected by limiting NGSO downlink power levels. These foreign systems range from point-to-point relay systems to radio modems for personal computers.

As noted in the NRC Report, coordination will be needed with respect to at least some of these terrestrial stations; however, the NRC Report does not indicate what the potential outcome may be. See NRC Report, Annex II to Attachment C, Section 4. As an initial matter, the costs of coordination with foreign users easily could run into the tens of millions of dollars in light of the costs of attending coordination sessions with over 100 countries and the substantial interference analyses that would be needed. For protection of mobile earth stations, the outcome of these coordinations ordinarily would be protection areas defining where interference would occur, as defined in CCIR Report 773, but there is no apparent way to apply these findings. Specifically, many of the interfering systems are mobile; thus, there is no way to know when such a station is within interfering range. In addition, some of these and other terrestrial systems emit signals that span the entire 2483.5-2500 MHz band (e.g., FM TV transmissions); thus, there would be no interference-free MSS channels within the protection area. Consequently, while interference from the over 700 U.S. terrestrial stations might be eliminated through a reaccommodation plan such as is being considered for PCS systems, it is not at all clear that the much more numerous interference problems in other countries can be solved.

Equally troublesome is the power limit needed for NGSO downlinks in order to protect incumbent terrestrial systems. Under the approach currently being investigated in Task Group 2/2, the applicable limit would be determined on a case-by-case basis in coordination, which would be triggered if the downlink power flux density ("PFD") exceeds a certain threshold value. As things stand, all of the NGSO systems would exceed the threshold value in every country, thus exacerbating the above-mentioned coordination costs. More importantly, the available studies that are gaining acceptance in Task Group 2/2 indicate that the PFD limits needed to protect most terrestrial systems are no higher than the coordination threshold value of PFD, such that none of the proposed CDMA NGSO systems would be able to operate at their claimed downlink power (or capacity) levels. At best, this limit precludes the possibility of providing the additional link power margin needed to provide effective service to handheld terminals and to minimize the extent of ISM interference.

3. Interference Between CDMA Downlinks and Radiolocation Systems

Potential interference to and from radiolocation systems (e.g., radars) is the least studied interference problem faced by the NGSO Applicants, probably because the radiolocation service does not operate in the 2483.5-2500 MHz band in the U.S. This could be the worst of all the interference problems, particularly since radiolocation transmitters typically radiate extremely high power that would "jam" all mobile earth stations within line-of-sight and perhaps somewhat over the horizon. At the same time, radiolocation systems typically are severely degraded by levels of interfering signals that would not be noticeable in other types of systems.

C. Design and Operating Constraints on Uplinks

1. Interference To and From Aeronautical Radionavigation Systems

Frequency sharing problems with respect to the Russian Glonass satellite and Swedish radar systems operating in the aeronautical radionavigation service have been addressed since the commencement of preparations for WARC-92. Currently, it is hoped that the Glonass problem may change from one of co-channel frequency sharing, which is not possible according to the analyses presented to date, to an adjacent band interference problem that can be solved through adoption of stringent standards for unwanted emissions from mobile earth stations.

A problem that has not been resolved, however, is interference to NGSO satellites from Swedish radar systems, which is likely to preclude reliable MSS operation over northern Europe. Specifically, when directed near an NGSO satellite, the high power radar transmissions will saturate the satellite receiver and preclude MSS communications in the return direction (i.e., transmission from a mobile terminal). However, because of satellite motion relative to the radar beam and the motion of the radar beam itself, the interference will be transient but repetitive. NGSO MSS advocates will have the opportunity to confront this problem at the ITU-R Task Group 8/3 meetings to be held in July and November of this year. At best, this problem can be characterized as a severe reliability problem for the NGSO MSS systems.

2. Interference To and From Systems in the Fixed Service

In accordance with Resolution 46 and Article 27 adopted by WARC-92, and consistent with U.S. actions in Task Group 2/2 of the ITU-R, interference between MSS uplinks and systems in the fixed service is to be prevented in the 1610-1626.5 MHz band through coordination in the case of interference from mobile earth station transmitters and through power limits on terrestrial stations in the case of interference to satellite receivers.[6] As stated by some foreign delegates to the Task Group 2/2 meeting held in January 1994, however, coordination of transmitting mobile earth stations with certain of the administrations operating fixed stations under RR No. 730 (mod WARC-92) will not be practical. This is because the minimum acceptable coordination area that TG 2-2 is likely to specify will include the territory of each of the 20 administrations listed in RR No. 730 as well as adjacent areas extending at least 100 km from those territories and there will be numerous terrestrial stations to be analyzed in the coordination process. The process of in-depth coordination of numerous mobile earth stations with at least 20 countries will be costly

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6 The NRC Report asserts that coordination may resolve potential interference problems. Although interference "Case 9R" and "Case 10R" defined in Attachment 2 to the NRC Report infers that interference from the fixed service to MSS satellites is addressed, the Report does not provide an assessment of these cases. It should be noted, however, that AMSC submitted an analysis of interference from the fixed service to GSO uplinks and urged the NGSO advocates to submit analyses for their systems because of the onerous nature of the interference for systems covering areas other than the U.S. No such NGSO analyses were submitted.

for the NGSO parties, the FCC if it is a party to the process, and the administrations operating fixed systems.

Moreover, by virtue of an Inmarsat contribution to TG 2/2, it is abundantly clear that interference from these fixed stations to NGSO MSS satellites will disrupt return link communications (i.e., mobile-to-feeder link earth station) persistently and over expansive geographic regions unless the power limits specified by Article 27 for terrestrial stations are radically reduced. See Document 2-2/22, "Interference from Fixed Service Transmitters into MSS Satellite Receivers - A Case Study" (January 25, 1994). This problem is compounded by the fact that under the current Radio Regulations, this interference may occur from fixed stations operating not only in the 20 countries listed in RR No. 730, but also the 29 countries listed in RR No. 727, without recourse on the part of NGSO operators.[7] The necessary tightening of these power limits likely would preclude fixed service operation, and so, either the fixed service will be displaced from the 1610-1626.5 MHz band or NGSO MSS uplinks will be plagued with disruptions within areas served by satellites that are visible from the territory of administrations operating fixed stations.

3. Interference to Radioastronomy

Perhaps the only interference problem that can be considered to be solved is the problem of interference to radio astronomy in the U.S.; however, that solution is costly. Implementation of the protective frequency assignment process summarized in the NPRM will require substantially more power computers in the network control system, particularly if technical access delay is to be limited to unnoticeable duration as best as possible. It will not be possible to turn on an NGSO mobile earth station and immediately place a call because the NGSO control system will first have to determine the location of the mobile earth station. This could take several minutes with some of the position determination approaches that have been proposed. Moreover, the solution to this problem established that NGSO mobile earth stations will not be operable in the vicinity of radioastronomy observatories. Although the amount of service area lost is small in this case, that unserved area accompanies the many other areas in which service cannot be provided for the various reasons outlined above.

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7 The fixed stations operating under secondary allocations in RR No. 727 must not cause harmful interference to MSS uplinks, the power limits in Article 27 notwithstanding. However, given that several fixed stations operating with both primary and secondary status may simultaneously interfere with an NGSO satellite, it may be difficult to determine that a particular interfering fixed station is largely responsible for a particular interference problem. This multiple interferer situation may prevail as a result of the large beamwidths of fixed station antennas operating in the 1610-1626.5 MHz band. See, e.g., ITU-R Recommendation 759.

D. Impact of NGSO Interference Problems

The above interference problems will have tremendous impact on NGSO systems that can be summarized in terms of geographic areas where service cannot be provided, other geographic areas where achievable performance and capacity are limited, and increases in the costs for construction and operation associated with mitigation of the solvable problems. Table 2 summarizes this impact.

E. AMSC's GSO System Does Not Encounter the Many Inter-Service Sharing Problems Faced by the Proposed NGSO Systems

Because AMSC's system is designed to serve only North America, it will not encounter many of the numerous interference problems faced by NGSO MSS operation throughout the world. The discrimination of AMSC's satellite antenna toward foreign countries and the large distance separations available between AMSC's mobile terminals and systems in foreign countries render non-existent the international sharing difficulties that the proposed NGSO systems face.

Table 2 - Summary of Impact of NGSO Interference Problems

INTERFERENCE INTERACTION	IMPACT ON NGSOs OF INTERFERENCE INTERACTION	
	Best Case	Worst Case
feeder link sharing	Suitable bands not yet identified	Suitable bands not yet identified
to and from fixed (1610-1626.5 MHz and 2483.5-2500 MHz) Area affected: outside U.S.	Same as worst case except to the extent that MSS operators are able to afford a buyout of incumbent systems (near term possibility) or the incumbent systems disappear through obsolescence (long term possibility). In addition to costs under worst-case, costs of buyout may be incurred.	Capacity and performance are severely limited by downlink PFD constraints and interference to uplinks, resulting in loss of market access and increase in service cost. Substantial costs incurred in coordinating with thousands of fixed systems.
to radio astronomy (1610-1626.5 MHz) Area affected: worldwide	Users cannot access MSS system while located 50-100 km from radio astronomy observatories. Network control system costs increased and technical access delay is increased.	Same as best case for US and countries with large geographical area. MSS forbidden in countries with small geographic area operating radio astronomy observatories as well as neighboring countries. Substantial loss of market access and increased service costs.
from ISM (2483.5-2500 MHz) Area affected: worldwide	CDMA mobile terminals unreliable in all areas, limiting market access.	CDMA mobile terminals unusable in urban and suburban areas and unreliable in rural areas. Market access extremely limited and service costs increased.
to and from radiolocation (2483.5-2500 MHz) Area affected: worldwide	Sporadic disruption of CDMA service within line-of-sight of radars.	Best case, plus assuming interference is not precluded through coordination, interference complaints are registered by radar operators, and *a posteriori* PFD constraints must be observed by CDMA systems. Service costs raised *in situ*.

DECLARATION

I, Thomas M. Sullivan, do hereby declare as follows:

1. I have a Bachelor of Science degree in Electrical Engineering and have taken numerous post-graduate courses in Physics and Electrical Engineering.

2. I am presently employed by the Computer Sciences Corporation and was formerly employed by the IIT Research Institute, DoD Electromagnetic Compatibility Analysis Center.

3. I am qualified to provide the technical information in the Comments of American Mobile Satellite Corporation and the Technical Appendix thereto. I am familiar with Part 25 and other relevant parts of the Commission's Rules and Regulations.

4. I received, in 1982, an official Commendation from the Department of the Army for the establishment of international provisions for the worldwide operation of mobile earth stations.

5. I am serving as the Rapporteur on MSS matters from Working Party 8D to Task Group 2/2 of the ITU-R and I participate in national and international fora addressing MSS issues, including Task Groups 8/3 and 4/5. I participated in the Commissions Above 1 GHz MSS Negotiated Rulemaking Committee.

6. I have first-hand experience in the international coordination of frequency assignments for mobile satellite systems.

7. I have been involved in the preparation of and have reviewed the Comments of American Mobile Satellite Corporation. The technical facts contained therein are accurate to the best of my knowledge and belief.

Under penalty of perjury, the foregoing is true and correct.

5 May 1994
Date

Thomas M. Sullivan

EXHIBIT A

AMSC Subsidiary Corporation
Exhibit A

AMSC Subsidiary Corporation's Positive Impact Upon The Domestic Economy

Summary

AMSC Subsidiary Corporation (AMSC) is a telecommunications company dedicated to providing satellite-based mobile communication services to the fifty states, the Virgin Islands, Puerto Rico and two hundred miles of coastal waters surrounding those territories. When fully operational, the AMSC system will provide access to mobile communications services across the United States through agreements with 155 cellular carriers, other communications providers and direct sales. AMSC's ventures will support nearly 27,000 American worker-years and contribute over $5.69 billion in total to the Gross National Product (GNP) during the years 1994-2000 alone.

Background

According to a Department of Commerce (DOC) report, "U.S. Industrial Outlook 1994," the forces driving the telecommunications industry toward creation of the National Information Infrastructure include advances in technology and a general demand for new communications services. In 1993 these forces generated approximately $250 million in revenue for the mobile satellite industry. Projections for 1994 indicate growth at a rate nearing 40%. This explosion in revenues for mobile satellite services is forecasted to persist throughout the 1990's as customer bases become firmly established and new satellites dedicated solely to mobile communications are launched.

AMSC designed its Geo-synchronous system to complement and interact with the existing wireless communications network. The system will provide ubiquitous communication services to a domestic coverage area of over 3,000,000 square miles. Rural and metropolitan areas within the United States will have immediate access to information and, thereby, improve American industrial productivity, encourage domestic technical advances and enhance emergency services available to network users. Finally, AMSC will act as an "on ramp" to the Information Super Highway and help revolutionize the way Americans do business and live their lives.

POSITIONS CREATED

The construction, launch and operation of the AMSC mobile communications system will require the dedication and expertise of an average of 2,016 American workers during the period of 1994-2000. Accordingly, AMSC anticipates significant job growth in the following employment sectors: (1) AMSC employees and consultants; (2) manufacturers developing the company's mobile terminals and antennae; (3) sales and distribution positions required to market the company's services; and (4) manufacturers of AMSC's satellite, launch vehicle and communications ground segment (CGS). In 1994 the combined figure of employees from these four segments will reach 634. By the year 2000 that number will leap to 2,763.

A majority of the positions created by AMSC will be created in the field of satellite telecommunications. These highly technical jobs will utilize the skills of the American work-force and generate substantial returns for the domestic economy.

AMSC Employees and Consultants

During the next seven years, an average of 446 AMSC employees and consultants will coordinate the details of the AMSC MSS system at the AMSC corporate headquarters in Reston, Virginia.

Mobile Terminal and Antenna Manufacturers

Westinghouse Electric Corporation and Mitsubishi Electric Corporation have been contracted to help design, construct and distribute satellite mobile telephones and equipment for AMSC's system. A total of 1,477 U.S. jobs will be created by the year 2000 in Austin, Texas and New Braselton, Georgia for the task of manufacturing the equipment required to operate on the AMSC system.

Sales and Distribution Positions

After launch of AMSC's first satellite (AMSC-1), as many as 624 positions will be created in the cellular and transportation industries to market and distribute services. This figure is based on the number of anticipated customers activated on the AMSC system by the turn of the century.

Satellite/CGS/Launch Vehicle Manufacturers

To develop a satellite communications system, AMSC entered into contracts with several strategic partners in the telecommunications industry. AMSC contractors will require an investment of over $426 million for the construction and launch of AMSC-1. Construction and operation of the AMSC system will require the skills of an average of 309 workers.

Hughes Aircraft Company, Spar Aerospace Ltd. and Lockheed Corporation are currently constructing the satellite and payload, scheduled for launch by General Dynamics Corporation. Westinghouse Electric Corporation entered into a contract to design and construct the communications ground segment (CGS). To complete that assignment Westinghouse will utilize several major subcontractors, including Digital Equipment Corporation (software), Northern Telecom Canada Limited (switches and cellular interoperability), EF Data Corporation (channel units), and Satellite Transmission System, Inc. (radio frequency equipment). Arthur Andersen & Co. has been retained to develop AMSC's management information and billing systems.

TOTAL ECONOMIC IMPACT

In the year 2000, the total number of positions created by AMSC, its strategic partners and in the sectors of sales and distribution will be 2,763. By factoring in the number of non-industry jobs resulting from the company's economic "ripple effect," AMSC's activity will result in the overall creation of 5,376 American jobs.[1] The aggregate worker-years for the period of 1994-2000 will total over 27,000.

During the years 1994-2000, AMSC's investment in the wireless communications infrastructure will impact GNP heavily. By combining AMSC's construction and service contracts with projected revenues for system usage and mobile terminal sales, the AMSC project will pour over $3.85 billion into the domestic economy. In addition, by using a standard DOC multiplier for GNP, AMSC's overall impact during that period will amount to over $5.69 billion.[2]

Date: May 5, 1994

1 A standard U.S. Department of Commerce (DOC) multiplier for telecommunications companies in the Washington, D.C. metropolitan area was used to determine the "ripple effect" multiplier.

2 A standard U.S. DOC multiplier for total dollar change in output for each additional dollar of output delivered to final demand was used to determine the impact upon Gross National Product.

AMSC Subsidiary Corporation
Employment Projections
1994-2000

Exhibit A

	1994	1995	1996	1997	1998	1999	2000
AMSC EMPLOYEES AND CONSULTANTS	283	375	404	439	487	547	588
SALES POSITIONS	9.74	222.36	280.05	368.51	460.03	624.31	569.42
EQUIPMENT MANUFACTURE POSITIONS	18.5	516	670.6	891	1134.5	1577.7	1477.4
SPACE SEGMENT POSITIONS	220	10	297	342	227	17	17
GROUND SEGMENT POSITIONS	87	87	162	312	87	87	87
NETWORK OPERATIONS POSITIONS	16	16	16	16	16	25	25
TOTAL DIRECT JOBS CREATED	634.24	1226.4	1829.7	2368.5	2411.5	2878	2763.8
INDIRECT JOBS CREATED	599.55	1159.3	1729.6	2239	2279.6	2720.6	2612.6
TOTAL	1233.8	2385.6	3559.2	4607.5	4691.1	5598.6	5376.5

NOTE: Numbers in the above chart represent people employed in conjunction with the AMSC mobile satellite communications system. Positions split between varying market segments are represented by fractions.

AMSC Subsidiary
Corporation
($ 1,000) Financial Impact, 1994-2000 Ehxibit A

		1994	1995	1996	1997	1998	1999	2000
Total Mobile Communications		1,899	37,691	129,697	227,767	332,839	451,953	562,829
Revenue								
Mobile Terminal Revenue		4,680	130,042	168,996	224,544	285,908	397,594	372,338
Space Segment:								
AMSC-1		44,911	10,135	400	600	60	60	60
AMSC-2		20,025	29,772	57,579	48,567	44,911	10,135	400
Ground Segment:								
AMSC-1		32,597	14,909	16,123	16,971	19,934	18,900	12,458
AMSC-2		2,754	5,933	21,105	28,424	32,597	14,909	16,123
Sub Total		106,866	228,482	393,900	546,873	716,249	893,551	964,208
Multiplier Effect		51,296	109,671	189,072	262,499	343,800	428,904	462,820
TOTAL/YEAR		158161.7	338153.4	582,972	809,372	1,060,049	1,322,455	1,427,028
					TOTAL CONTRIBUTION			
					TO GNP (1994-2000)			5,698,191

EXHIBIT B

ECONOMIC AND TECHNICAL CONSIDERATIONS OF A GSO GLOBAL MSS (TRITIUM)

Pacific Telecommunications Conference
January 12-15, 1992
Honolulu, Hawaii

Dr. George Hrycenko, Dr. Klaus Johannsen,
Patrice Louie, and William Lucas
Hughes Aircraft Company, Space and Communications Group

Summary

This paper reviews a study of an advanced geosynchronous orbit (GSO) mobile satellite system (Tritium), which offers an alternative to the recently advocated low earth orbit (LEO) operational proposals. The study illustrates that the improvements featured by LEO mobile satellite system (MSS) configurations can be better provided by GSO communication relays and at a substantially lower cost. In fact, on a per-channel basis, geosynchronous systems offer similar service that is an order of magnitude less expensive than low earth orbit alternatives. The issue of hop delay is not a significant factor when assessing market demand since the majority of potential users will have, at best, limited access to substitutes. The inherent flexibility of GSO systems provides a unique ability to adjust to evolving market demographics. These factors allow geosynchronous MSS to offer the most affordable service that satisfies the public demand.

Furthermore, the study concludes that advanced GSO MSS capabilities can be implemented with more conventional technology, which offers longer life and less operational complexity. These GSO system service features not only offer equivalent performance and substantially improved reliability, but also provide compatibility with equivalent low cost mobile terminals proposed for LEO's with the same global connectivity. Most important, the advanced GSO system features improved spectral efficiency over currently operational MSS configurations and over some of the new LEO contenders.

Introduction

The Tritium mobile satellite concept is a geosynchronous approach to providing global cellular radio communication. It features mobile-to-mobile user and mobile-to-fixed user communication. Tritium achieves global coverage by three GSO satellites, separated 120° in orbit; each satellite covers its part of the earth with up to 160 beams. The inbeam and interbeam connectivity is provided by Ku-band backhaul links and by earth based switching. The power spectral flux densities at the earth's surface produced by the Tritium satellite beams will not exceed the maximum values set forth by the Radio Regulations. The maximum capacity per satellite is 30,000 links and the total Tritium system capacity is about 90,000 duplex circuits. This capacity is placed where it is needed, namely over populated areas, whereas 85% of the advertised total Iridium capacity of 285,000 circuits is placed over largely unpopulated areas or is unusable. Therefore, the three satellites of the GSO Tritium system have nearly 50% more effective capacity as the 77 satellites of the Iridium LEO MSS.

System Economics

In an effort to compare the relative strengths and weaknesses of low earth orbit (LEO) and geosynchronous orbit (GSO) satellite systems for mobile communications, attention must be given to the economic considerations governing their construction and launch. It is true that each LEO satellite is significantly cheaper to build and launch than a GSO satellite for systems of similar capability. Yet, given the fact that low earth orbits require many more spacecraft for complete earth coverage, and because LEO satellites last approximately 40%-50% as long in orbit as GSO satellites, the total number of spacecraft over the system's useful life will be substantially more. This generates a much higher cost to build and operate a LEO system over a similar period than a comparable GSO system.

Arguments have been made about the benefits of the "learning curve" when building large quantities of essentially identical spacecraft. We have found that although such downstream savings do occur, they tend to be relatively small and are often overshadowed by the huge investment in research and development. In fact, Motorola estimates that the average nominal flyaway cost of the replacement satellites for Iridium do not generate any recurring savings on average. If the non-recurring costs are applied to the initial constellation, the learning curve generates no more than a 20% savings[1].

Table 1 illustrates the relative costs of building and launching different types of communications systems; two low earth with polar orbits and one geosynchronous. It is obvious that, on a per-unit basis, LEO spacecraft are substantially cheaper to build and launch. In addition, launch costs to geostationary transfer orbit are, on a per pound basis, roughly double those to low earth orbit. The extra weight of kick motors and hydrazine fuel boosts the total launch cost for each GSO spacecraft to many times the cost of each LEO satellite. However, because a GSO system requires only 2%-3% of the total number of LEO satellites over the life of the system, the aggregate costs to manufacture and launch a geosynchronous constellation are substantially less than Iridium and only double those of Aries, a system with far less capability.

When comparing costs per usable channel, it is even more readily apparent that a GSO system is, by far, the most economical solution. A major benefit espoused by LEO proponents is the fact that only low earth orbit systems offer total earth coverage. Because the highest latitudes are out of the range of visibility of GSO satellites, these systems cannot offer coverage near the poles. We have found, however, that, except for some marginal airline traffic over the northern polar regions, less than 0.5% of the world's population (primarily over Russia) is excluded from geosynchronous coverage[2]. Of the greater than 99% of the addressable market positioned within the realm of GSO systems, only about 5% exists over the oceans and about 3%-5% over the polar regions (roughly 1% from maritime traffic and approximately 7%-9% from intercontinental airline traffic). LEO systems, by their nature, must cover the globe with uniform capacity as they travel over the entire surface. Geosynchronous satellites can be tailored so that only a small percentage of the available channel capacity sits over the oceans. In addition, the proximity of low earth orbiting spacecraft over the poles causes significant beam overlap at the higher latitudes. Because of this, only 56% of Iridium's cells are turned on at any one time[3]. Other low earth, polar orbit systems suffer similar inefficiencies. Consequently, the combination of polar beam overlap and redundant ocean coverage reduces the effective capacity of a typical LEO communications system by over 80%. Therefore, instead of a possible three-fold advantage in system capacity, low earth

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1 Global Personal Communications Satellite Services: *Benefits of a Low Earth Orbit Constellation over a Geostationary Earth Orbit System*, Oct. 8, 1991, p.17.

2 The World Almanac and Book of Facts, 1992.
The Times Atlas of the World, 7th Edition.

3 Leopold, Dr. Raymond J., Low Earth Orbit Global Cellular Communications Network, Aug. 23, 1990, p. 7.

TABLE 1. LEO-GSO System Cost Comparison

PARAMETER	IRIDIUM LEO	TRITIUM GSO	ARIES[1] LEO
# of Satellites	77	3	48
Standby Satellites	7	1	4
Total # of Satellites per Life Cycle	84	4	52
Satellite Design Life (Years)	6	12	5
# of Satellites per 12 Years	220	4	136
Cost per Satellite ($M)	$13.4	$150.0	$3.0
Cost of Fleet for 12 Years ($M)	$2,948	$600	$408
Dry Weight per Satellite (lbs.)	950	6,200	275
Launch Cost per Satellite ($M)	$6.0	$194.0	$2.9
Total Launch Cost ($M)	$1,317	$776	$394
Insurance Rate	7%	18%	7%
Insurance Cost ($M)	$299	$248	$56
Total Space Segment Cost	$4,564	$1,624	$858

orbit systems have a total number of usable channels that is from 40% to 99% less than a comparable GSO system. Consequently, the cost per effective channel to implement and operate a LEO system is significantly greater. Table 2 illustrates this case in point.

In addition to cost, there are some practical tradeoffs that must be addressed. Hop delay is a seemingly unavoidable problem with geosynchronous telephony. However, as Motorola defines the addressable market, potential users will consist of those in need of emergency communications, those who have no available mobile service, those who have no telephone service at all, and those whose only mobile satellite service comes from geosynchronous spacecraft[2]. It is a well known fact that people who do not have access to a particular service and yet who desire that service will pay for it, even though the quality is inferior to better, but unavailable substitutes. Every segment described above, except for the last, defines just this situation. In fact, users of Intelsat request a circuit change only 12% of the time when presented with an alternative[3]. Therefore, from a business viability standpoint, we have not yet seen a compelling argument demonstrating the negative effects of hop delay on the mobile satellite business. Demand should not be appreciably affected in the projected markets serviced by these global systems. Since a GSO system can be implemented less expensively, it should indeed be built since the savings will go to the consumer by way of lower service costs.

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1 Aries FCC Filing, June 3, 1991.

2 Leopold, Dr. Raymond J., Low Earth Orbit Global Cellular Communications Network, Aug. 23, 1990, p. 2.

3 Global Personal Communications Satellite Services: *Benefits of a Low Earth Orbit Constellation over a Geostationary Earth Orbit System*, Oct. 8, 1991, p.13.

TABLE 2. LEO-GSO Cost per Channel Comparison

PARAMETER	IRIDIUM LEO	TRITIUM GSO	ARIES[1] LEO
Channels per Satellite	3,700	30,000	50
# of Satellites	77	3	48
Total System Capacity (Channels)	284,900	90,000	2,400
Reduction for Beam Overlap	0.56	1.00	0.57
Reduction for Ocean Coverage	0.29	0.90	0.29
Capacity Used by Maritime and Airline Traffic	1.10	1.01	1.10
Channel Usage Efficiency	18%	91%	18%
Effective System Capacity (Channels)	50,900	81,810	436
Total Space Segment Cost ($M)	$4,564	$1,624	$858
Total Space Segment Cost per Channel	$90,000	$20,000	$2,000,000

The second and perhaps the most important factor to consider is the inherent flexibility of a GSO system. The fact that the marketplace is dynamic and unpredictable warrants a set of satellites that can alter beam configurations and power requirements as demand concentrations change. A geosynchronous spacecraft can be tailored to the needs of the market. Intra-beam capacity can be altered from the ground without affecting the balance of the system because each cell remains stationary. LEO satellites must maintain constant power levels and channel capacities since they move over different areas of the globe. If local market demand evolves beyond the capacity of the satellites to absorb the changes, a LEO system will not be able to efficiently serve its customer base.

Finally, if the market does not develop as quickly in certain regions of the world, a GSO approach allows the phased implementation of the system by launching spacecraft only where they are immediately needed. This facilitates a workable system with only partial coverage. A LEO system, on the other hand, must be nearly fully launched in order to avoid unacceptable delays and sporadic connectivity. This increases the required initial investment to launch the business, even if demand does not warrant that level of available capacity.

Instrumentation

Hughes has recently studied a GSO MSS system, Tritium, which reflects the cited economic advantages. Nominal satellite locations for Tritium are 100° west, 20° east, and 140° east. These positions guarantee that all continents are covered, and that visibility crossover for a 5° elevation angle occurs at high latitude (62°) (Figure 1).

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[1] Aries FCC Filing, June 3, 1991.

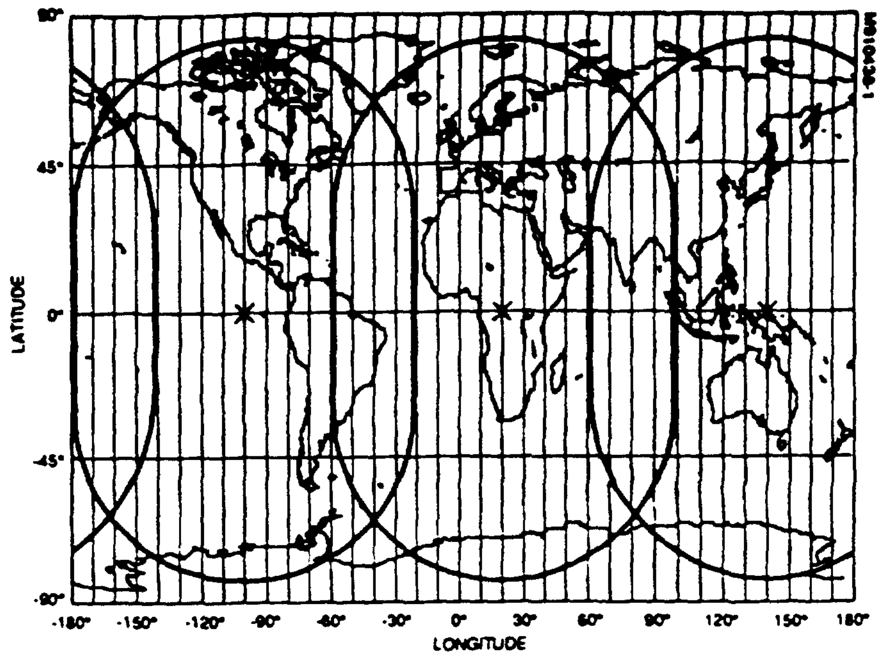

Fig. 1 Tritium system coverage

The global view from synchronous altitude is about 18°. With beams of 1° beamwidth, which can be obtained by use of a 55-foot antenna, visible earth coverage is achieved with about 290 beams. If only land masses are to be covered, the number of beams is 120 to 130, depending on which part of the world the satellite is located. Satellite weight and power constraints limit the number of beams to about 160. For full earth coverage, some ocean coverage beams are combined to form beams of 2 to 3° (Figure 2).

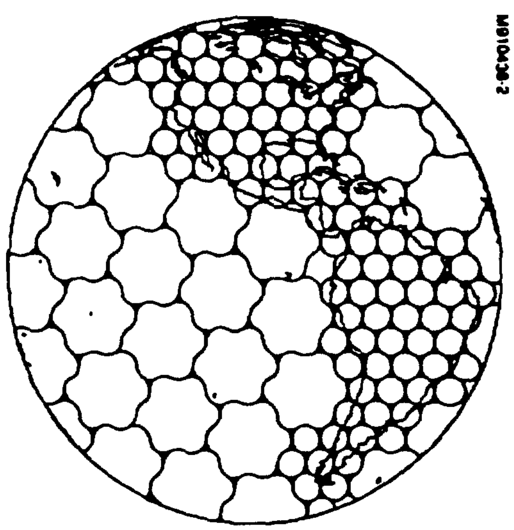

Fig. 2 America coverage beam zones
for satellite location at 100° w

A satellite that provides cellular radio service by so many beams requires a lot of independent signal paths that do not cause mutual or intercell self-interference. Difficult functions of a multibeam satellite are diplexing of transmit and receive frequencies, interbeam connectivity, and RF-power distribution. Diplexing for a large number of beams can run into weight and space limitations. Therefore, one approach to avoiding diplexing would be to transmit and receive at time-interleaved intervals on the same frequency; this approach would also avoid passive intermodulation. Of course, it would require exact timing of the total network and digital burst transmission. But, with solid state power amplifiers (SSPAs), there are instrumentations available that assume some of the diplexing functions. The SSPAs produce low levels of intermodulation and cancel the out of band transmission, thereby avoiding the active intermodulation that falls into the receive band. Besides active intermodulation, there is passive intermodulation (PIM), which may fall into the receive band. Based on preliminary studies, it has been concluded that a certain amount of PIM can be tolerated and that dual frequency operation, i.e., separate frequencies for transmission and reception, is preferable over single frequency operation and precision transmission timing.

One of the most important decisions in making up a repeater architecture is to choose the method of interbeam switching. After careful system analysis, it has been concluded that with up to 160 elemental beams, the onboard processing required for complete interconnectivity is too complicated and the switching and processing functions have been relegated to the ground. The implication, of course, is a long transmission time delay (about 600 ms) because the signal travels four times the length of the geosynchronous altitude. However, as cellular traffic studies have shown, the majority of mobile traffic occurs between mobile and fixed locations, cutting the transmission delay in half, to about 300 ms.

The distribution of RF power in the various beams is another vexing problem. It would be advantageous if all the amplifiers could amplify all the signals, but this requires complex Butler matrices and fixed delays among antenna elements. Instead, it has been decided to have independent amplifiers (one per feed element) where the amplifiers have constant efficiency and use power only according to the number of applied carriers.

CDMA was selected as the preferred access approach since it offers the greatest frequency reuse and voice channel capacity. Also, CDMA is less susceptible for both multipath and multibeam interference, partly because interference adds mostly as noncoherent noise and partly because it can use a higher rate FEC and, therefore, a low Eb/No, without widening the bandwidth. Although FDMA has historically been preferred, today's microchip technology favors CDMA.

The mobile user who tries to make a connection has to ask for service on one of the network control channels, which is unique for any beam. By transmitting on one particular control channel, the network control center knows where the vehicle is located and will allocate a voice or data channel in that particular beam. If a mobile user is to be contacted, one has to know the position of the vehicle. For this purpose, its access code will be broadcast on all beams or in certain beam sectors where the user might be situated at that time. The user's response will indicate its position. Also, the position of mobile users can be obtained either by the user's forwarding position information, or by having the network control center monitor the control channels and memorize the last position. For network control and interlinking, all global and local area network control stations will be interconnected by Ku-band links.

CDMA and Mainlobe Interference

Studies show that CDMA mainlobe interference is the primary source of degradation and sidelobe interference is of secondary concern. Since CDMA must use a wide bandwidth for interference rejection, one cannot slice up the total transmission bandwidth into small pieces. If one uses a

14 MHz band, each beam has the same frequency, and a user at the crossover of three beams suffers the interference from 3n-1 friendly users. In the satellite visibility crossover zone the interference would double unless different polarizations are used on adjacent satellites. If the band is divided into three frequencies, adjacent beams do not have the same frequency and the user at the crossover zone of three beams suffers only the interference of n-1 friendly users. However, the WT product, i.e., the transmission bandwidth times the bit period product is lower because the spread bandwidth W has been divided by 3 and, consequently, the interference rejection is reduced. Analysis shows that it is better to use the larger bandwidth and accept the 3n-1 interference than to reduce the bandwidth. Since each beam uses the full 14 MHz, about 64 beams will fill up 1000 MHz. To accommodate 160 beams 2500 MHz are required, which must be partitioned among several Ku-band earth stations residing in different geographical areas and operating on a dedicated Ku-band spot beam.

CDMA Links

The L-band and Ku-band beam EIRP budgets are given in Table 3. The edge of earth L-band beams have a 4 dB gain defocusing loss. Table 3 also shows the expected gain over temperature ratio (G/T) budgets of both L-band and Ku-band receivers.

TABLE 3. TRITIUM EIRP AND G/T BUDGETS

Parameter	L-band EIRP, dBW		Ku-band EIRP, dBW
	Edge Beam	Center Beam	
HPA output power, dBW	9.0	10.0	14.0
Output losses, dB	-1.3	-1.3	-2.0
Antenna gain, dB	41.3 (EOC)	41.3 (EOC)	35.0 (Center)
Scan loss, dB	-4.0	0.0	0.0
EIRP per beam, dBW	45.0	50.0	47.0 (max)
	L-band G/T, dB/K		
	Edge Beam	Center Beam	Ku-band G/T, dB/K
Antenna Gain, dB	41.0 (EOC)	41.0 (EOC)	35.0 (Center)
Scan loss, dB	-4.0	0.0	0.0
System temperature, dBk	28.0	28.0	28.0
G/T, dB/K	9	13	7.0

CDMA link performance calculations represented in Table 4 show that with a rate 1/3 FEC and a WT product of 34.5 dB all CDMA links can support 125 to 250 carriers per beam, depending on beam pointing, and that CDMA provides a high link margin (4 dB) against its own low Eb/No of 4 dB. The CDMA links also indicate that it is best to use the widest bandwidth for optimum signal to noise ratio. It should be noted that signals transmitted

TABLE 4. TRITIUM LINK BUDGET, CDMA

Downlink	L-band (edge beam) (1550 MHz)	L-band (Center Beam)	Ku-band Downlink
RF power per beam, dBW	9.0	10.0	14.0
Backoff, dB	—	-	−4.0
RF loss, dB	−1.3	−1.3	−2.0
Antenna gain, dB	41.3	41.3	35.0
Scan loss, dB	−4.0	0.0	−1.0
Total EIRP per beam, dBW	45.0	50.0	42.0
No. of carriers, dB	−21.0	−24.0	−36.0
	125 channels	250 channels	4000.0 channels
Voice activation, dB	4.0	4.0	4.0
EIRP per carrier, dBW	28.0	30.0	10.0
Path loss, dB	−188.8	−187.4	−205.6
Receiver antenna gain, dB	+4.0	+4.0	50.0
Received carrier, dBW	−156.8	−153.4	−145.6
K, dBW/kHz	−228.6	−228.6	−228.6
B, dB/Hz	71.5	71.5	71.5
T, dBk	24.0	24.0	22.0
N, dBW	−133.1	−133.1	−135.1
(C/N) d, dB	−23.7	−20.3	−10.5
C/IM, dB	−2.0	−2.0	−2.0
C/I (side lobe), dB	−14.0	−14.0	—
(C/N) up, dB	−16.5	−16.5	−22.3
Cochannel interference, dB	−21.8	−24.8	−24.8
C/N, dB	−26.5	−26.5	−26.5
WT, dB	+34.5	+34.5	+34.5
Eb/No, dB	8.0	8.0	8.0
Eb/No required, dB	4.0	4.0	4.0
Margin, dB	4.0	4.0	4.0
Power flux density in 4 kHz, dBW/m^2	−154.0	−149.0	

C/IM = NPR—number of channels in beam (15–17) = −2 dB

(C/I) per beam = C/I —number of interfering sidelobe beams—number of channels

= 13-10-17 = −14 dB

from cell to cell are going up in L-band, then down in Ku-band to the network switching center, where signals will be demodulated and remodulated and noise will be removed. Therefore, there is only one hop of effective satellite link noise to be accounted for. The L-band downlink carrier to spectral noise density received through a 4 dB gain antenna is 45 dB Hz. The edge beam power flux density in 4 kHz on the earth surface is -154 dBW/m^2, which meets Radio Regulation requirements at 0° to 5° elevation. The center beam produces a power flux density of -149 dBW/m^2 per 4 kHz, which is 5 dB below the maximum allowable limit of -144 dBW/m^2 per 4 kHz at high elevation angle.

The number of channels per beam can also be calculated from the following equation:

$$mCDMA = \frac{(No/Eb)\ WT}{a\left[l(1+\frac{1}{K})\ Afb + (N/CT)d + l\ (N/CT)Kuup\right]M}$$

where

(N_o/E_b)	=	Required noise density to bit energy ratio
(N/CT)Ku up	=	Noise to total power ratio of the Ku-band uplink
(N/CT)d	=	Noise to total power ratio of the downlink
WT	=	RF bandwidth ¥ bit-period
l	=	1.04 degradation in detection due to IM (at 15 dB NPR)
K	=	10 Gaussian fading factor
Afb	=	3.4, main lobe and sidelobe interference factor
a	=	Voice activation factor (0.4)
M	=	Link margin

Tritium-CDMA Communications Payload

The Tritium-CDMA repeater is shown in Figure 3. In case of the forward link, Ku-band signals are transmitted from several master control stations (MCSs) within two 500 MHz bands (per beam), in two planes of linear polarization in 14 (15.6) MHz slots, and are downconverted to C-band. From C-band they are further downconverted to L-band, where filters will select a 14 MHz band associated with each L-band beam. After filtering, signals will be fed to the transmit chain, which consists of channel control unit/linearizer and a 10 W SSPA. The amplified signals are then routed to the L-band diplexer and from there to the L-band feed. On return, L-band uplink signals, collected by a single beam, are amplified and filtered by 14 MHz filters. Then, the elemental beam bands of 14 MHz each are converted to C-band. Up to 64 bands of 14 MHz are combined by an odd-even output multiplexer, after which separate bands of 32 X 15.6 = 500 MHz are upconverted to Ku-band and transmitted to the MCSs, which are in different parts of the satellite viewing area. For the purpose of interconnecting all network control and gateway stations and for interlinking, there is a Ku-Ku-band interconnection and distribution network. At the MCS, inbeam and interbeam switching and other operations which are necessary to clean up transmission are performed.

One building element necessary for the success of a Tritium-like satellite mission is the HPA with constant efficiency. Constant efficiency means that over a wide dynamic input power range the HPA requires a dc power proportional to the applied input power. Thus, when amplifiers do not require the allocated average dc power, the excess is available to other amplifiers, which may have

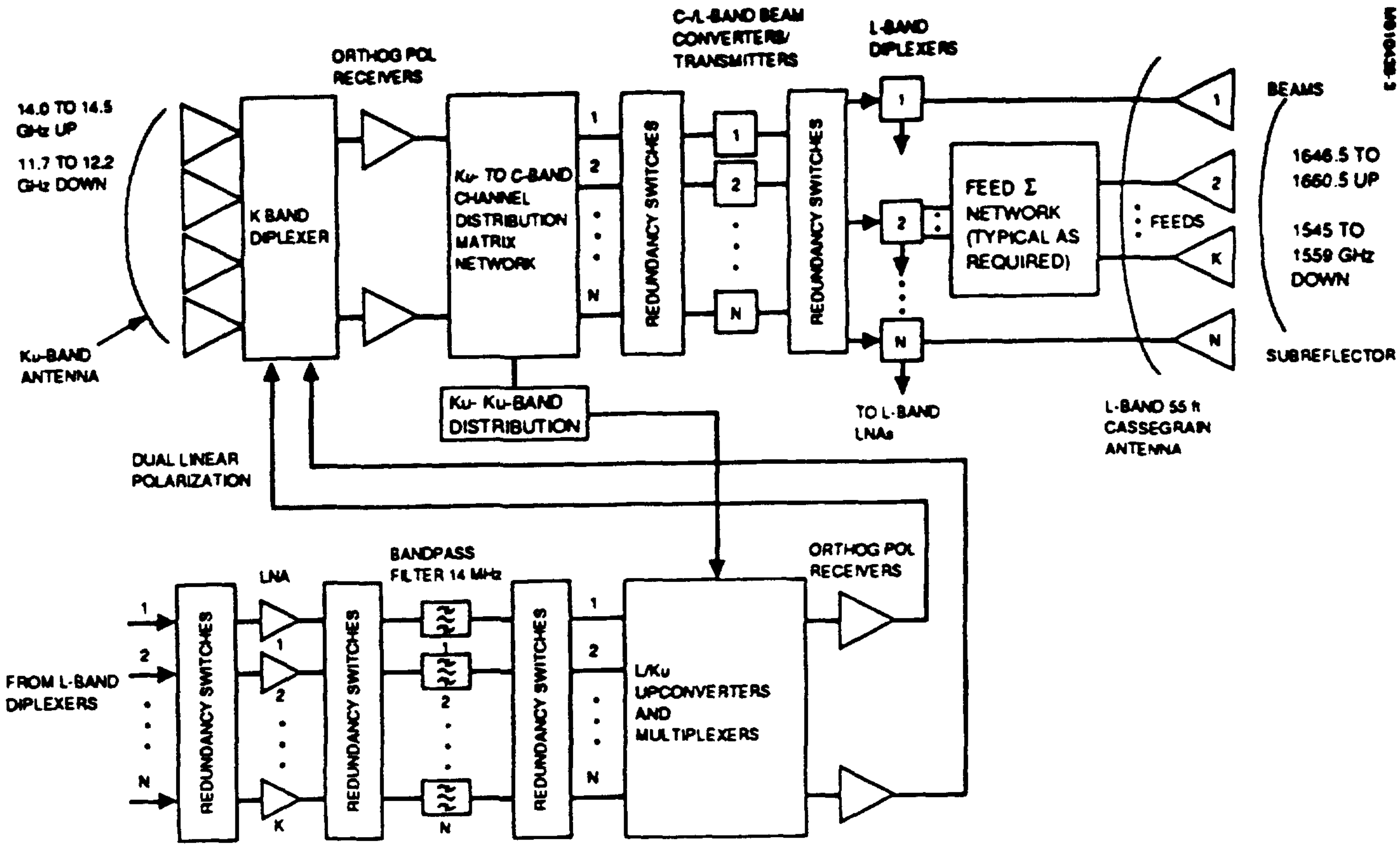

Fig. 3 Transponder

a higher carrier demand. Thus, there is a limited dc power transfer available from those amplifiers with little traffic to those with above average traffic. The center beams have a 5 dB dynamic range margin before their flux density limits are reached.

The L-band antenna consists of a 55 feet cassegrain reflector, which is attached to the body-stabilized Hughes HS 601 bus, and a subreflector, which is held in place by a tripod. The Ku-band antenna is mounted on the other side of the subreflector. The reflector is constructed of a wire mesh, which permits sunlight to reach the solar panels.

Tritium System

The link calculation shows that 125 mobile voice links of 4.8 Kbps can be supported by beams at the edge of the satellite visibility zone and 250 links can be supported by beams at the sub-satellite points. The Ku-band link is laid out for the average expected traffic of 160 beams or 160 X 187.5 @ 30,000 carriers. This requires a total Ku-band width of 160 X 15.6 = 2500 MHz. If this bandwidth is distributed among 10 gateway stations, each station has to transmit on its Ku-band link less than 250 MHz.

The payload weight and size is such that an Ariane 5 launch vehicle is required. A sketch of the Tritium satellite is given in Figure 4.